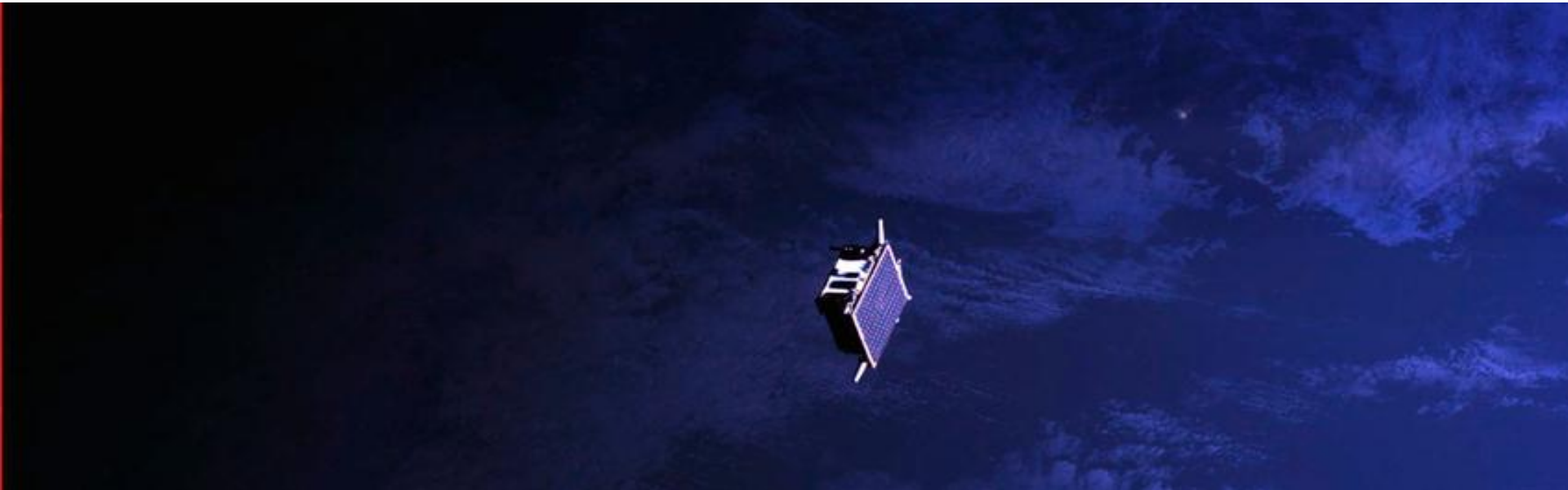


Development of Green Propellants - HPGP Technology



Mathias Persson, President, ECAPS

2011 International Workshop on Environment and Alternative Energy
ESTEC, November 15, 2011

www.sscspace.com/ecaps



ECAPS

- Is a fully owned subsidiary to SSC (Swedish Space Corporation)
- Main objectives: To develop, manufacture and market reduced hazard propulsion systems
- Long term vision: “By innovations and product development increase accessibility to space by safe and cost effective systems”
- Supported by ESA, SNSB and the owner SSC through all development programs

Products

1N HPGP Thruster (TRL7)

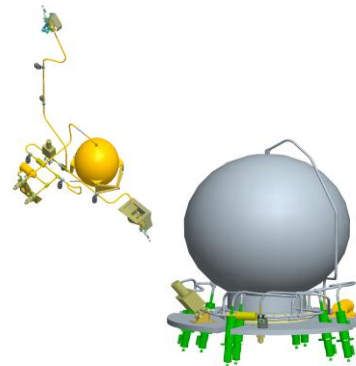
5N HPGP Thruster (TRL4/5)

22N HPGP Thruster (TRL4/5)

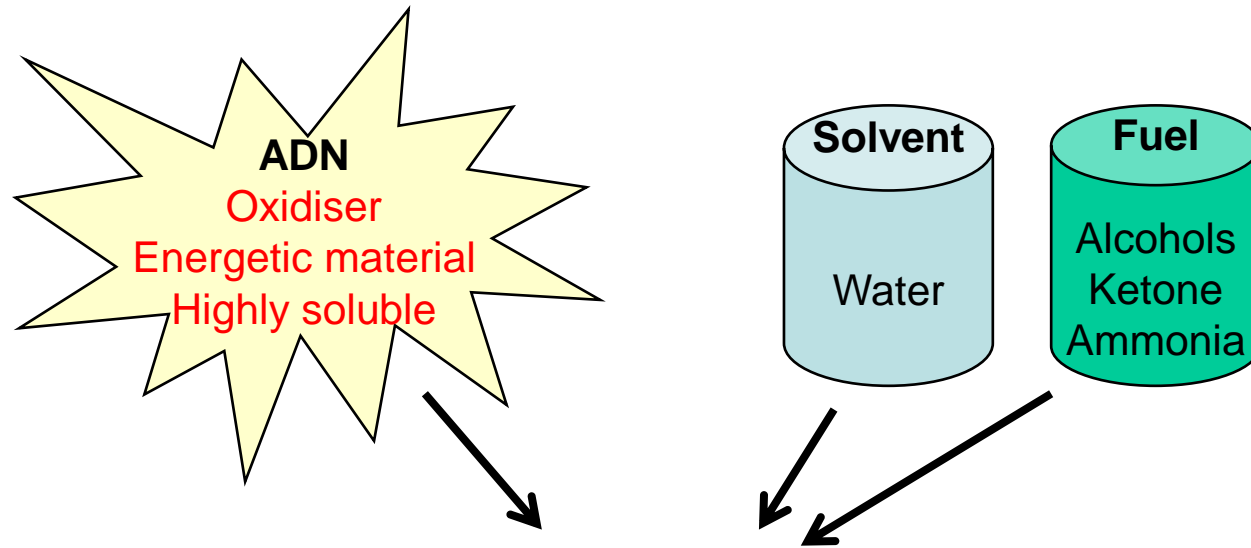


LMP-103S Liquid Monopropellant

HPGP Propulsion Systems



ADN in Liquid Monopropellants



Invented in 1997 by the Swedish Space Corporation (SSC) and the Swedish Defence Research Agency (FOI).

("a pre-mixed Bipropellant")

Careful selection of solvent and fuels makes the **ADN-solution much less sensitive than pure (solid) ADN.**

High Performance Green Propulsion - HPGP

A space proven alternative to Hydrazine propulsion giving:

- **Better Performance and Characteristics**
 - Storable Liquid monopropellant
 - High Specific and Density Impulse
 - Good pulse performance
- **Higher Safety**
 - Low Sensitivity
 - Low Toxicity
 - Non Carcinogenic
 - Environmentally Benign
- **Lower overall mission cost**
 - Easy to handle and transport
 - Low cost for fuelling
 - Compatible with available COTS

Propellant Development Time-line

1999

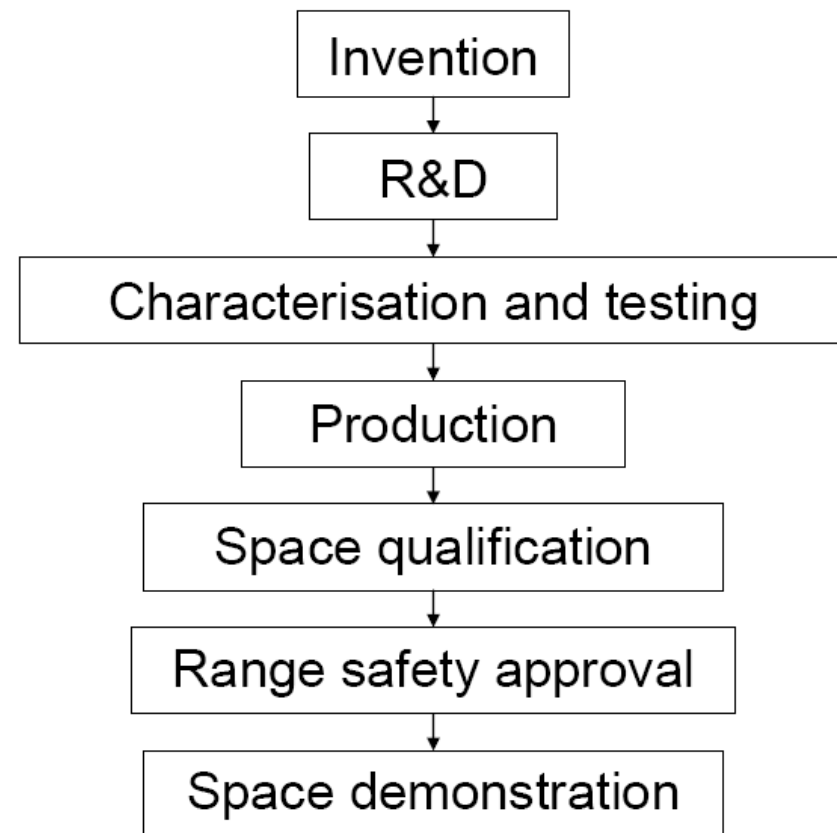
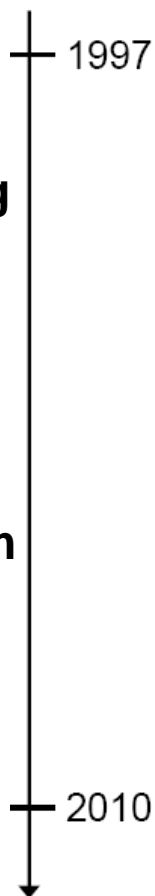
First HPGP Thruster hot-firing

2007

First HPGP propulsion system delivered – PRISMA

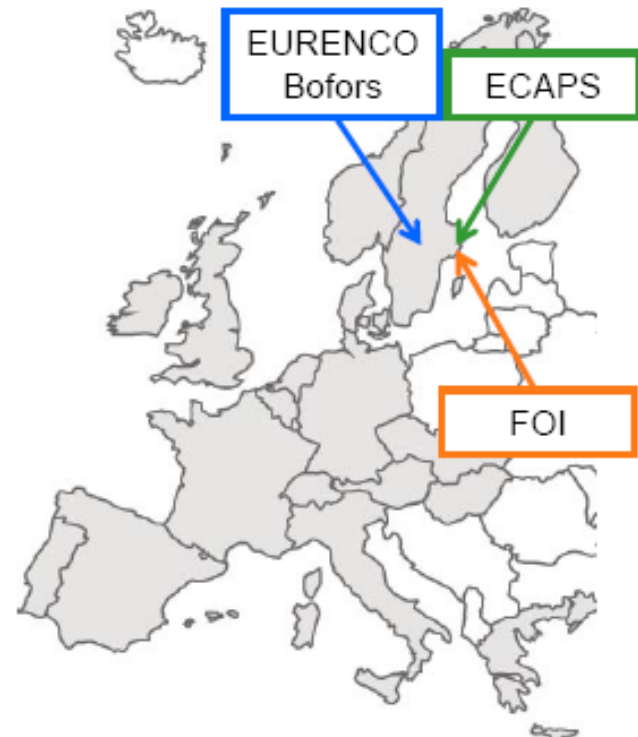
2010 PRISMA Launch

2011 HPGP test objectives accomplished



ECAPS Locations

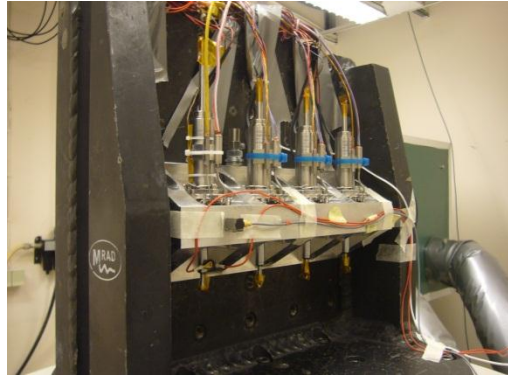
- Rocket engine development and manufacturing at ECAPS in Solna
- Propellant production and testing at EURECO Bofors in Karlskoga
- Rocket engine and propellant testing at FOI in Tumba



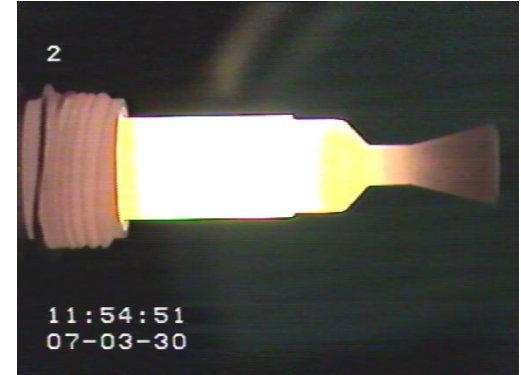
Solna - Thruster Manufacturing, Assembly & Test



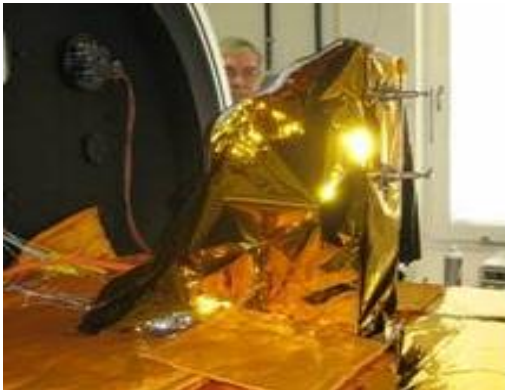
Thruster Assembly



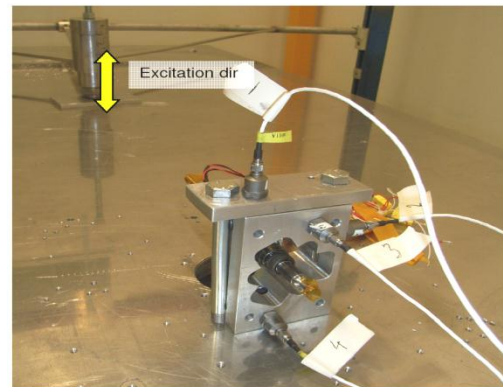
Vibration Test



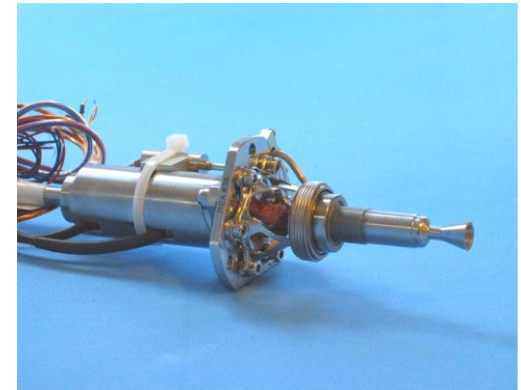
Hot Firing Test



Sun Simulation Test



Shock Test

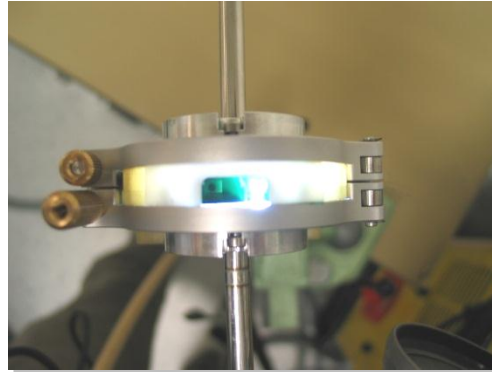


PRISMA Flight Qualified

Solna - System Manufacturing, Assembly & Test



Tube bending



Orbital welding



Precision Cleaning



X-ray



Pressure and Leak Check



HPGP Flight System

Karlskoga – Propellant Manufacturing

- EURENCO Bofors is the largest producer of ADN
- Space applications require high purity propellants, i.e., $> 99.999\%$ purity * (“standard” ADN is $\sim 99.6\%$).
- An ADN purification process has been developed by EURENCO Bofors and ECAPS, which fulfils the high purity requirements.
- A pilot-plant-scale purification system is operational, owned by ECAPS and operated EURENCO Bofors.



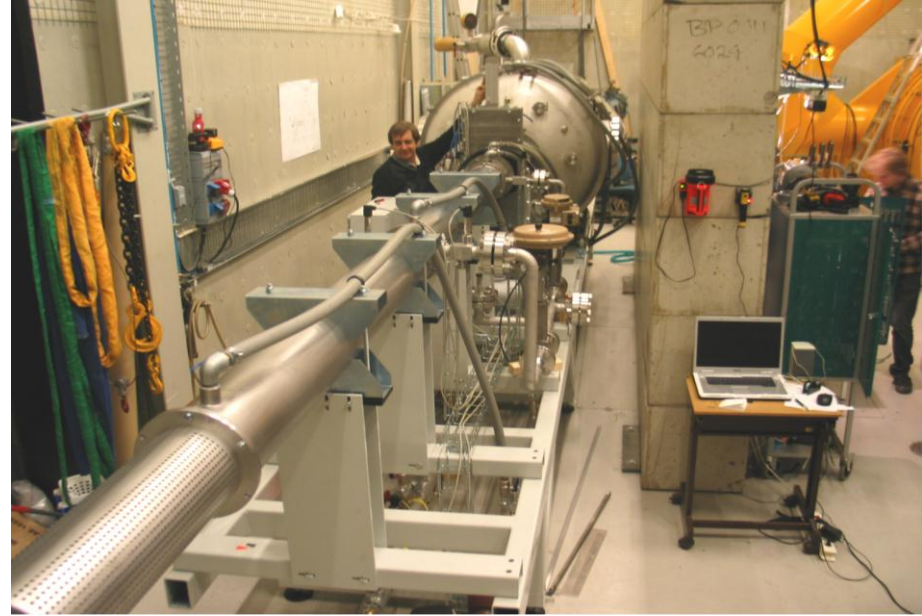
Grindsjön - Hot-Firing Test Facility

Test Stand 1 0.2 – 5 N



2 Stage Roots Blower/Pump
Ambient ≤ 1 mbar @ 1N (i.e 0.5 g/s)
Ambient ≤ 5 mbar @ 5N (i.e 2.5 g/s)
Test Duration @ 1 N up to 5 hours

Test Stand 2 5 – 22 N (500 N*)



3 Stage Air Ejector Pump
Ambient ≤ 5 mbar @ 200 N
Test duration @ 22 N up to 1 hour
(Test duration @ 500 N up to 15 minutes)*

LMP-103S

ADN-Based Liquid Storable "Green" Monopropellant

Higher performance:

- Isp >6%
- Density Impulse >30%

Reduced personal and environmental hazards:

- Low sensitivity
- Low toxicity
- Non carcinogenic

Simpler to transport and handle:

- SCAPE not required
- Approved for air transportation

ADN

+

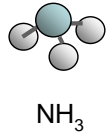
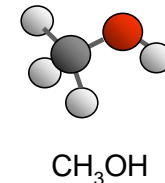
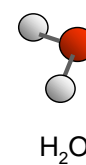
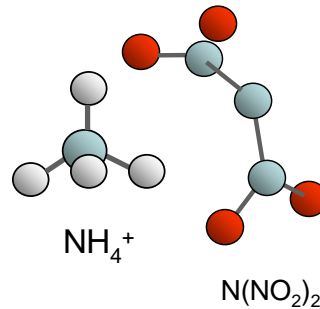
Solvent

+

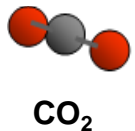
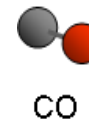
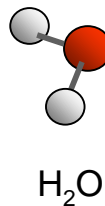
Fuel

+

Stabilizer



Exhaust species



HPGP / LMP-103S Technology

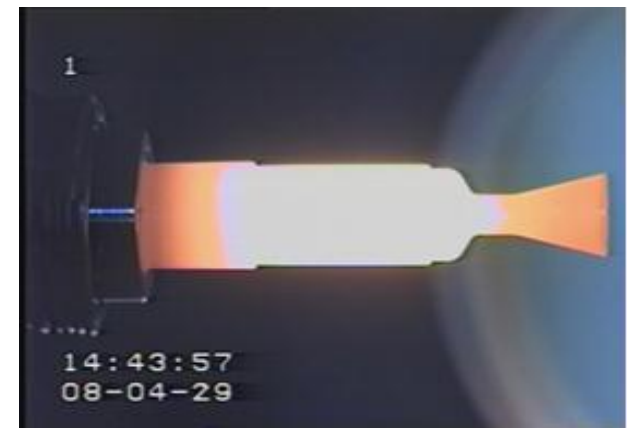
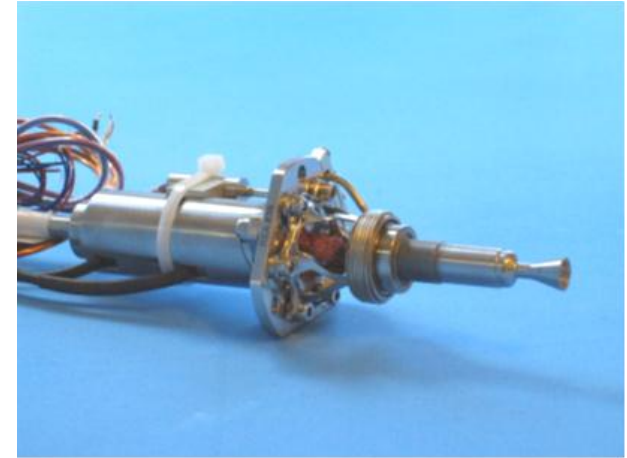
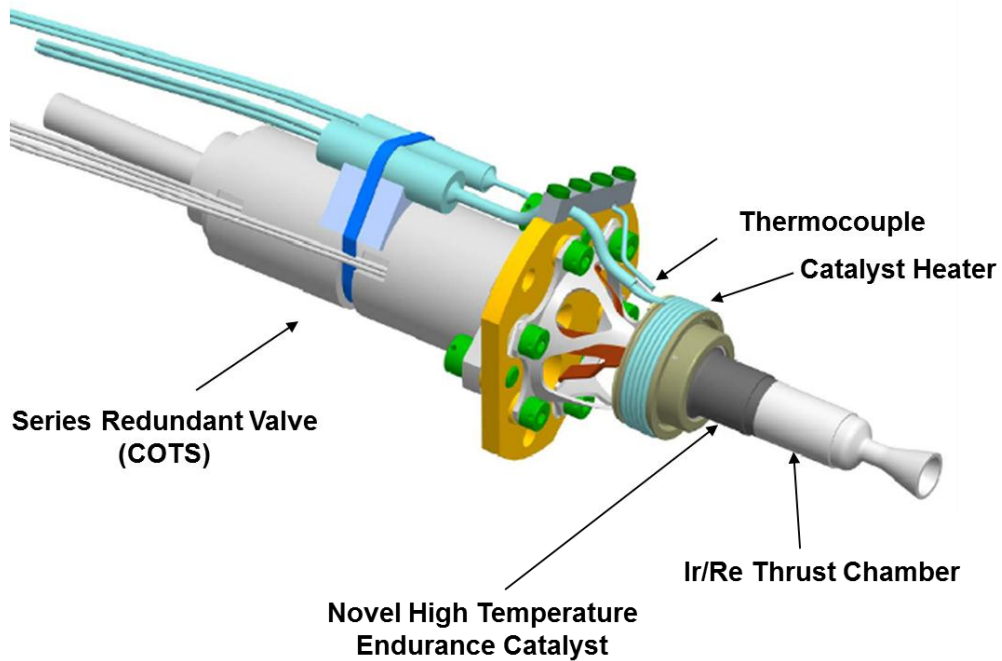
Propellant Transport



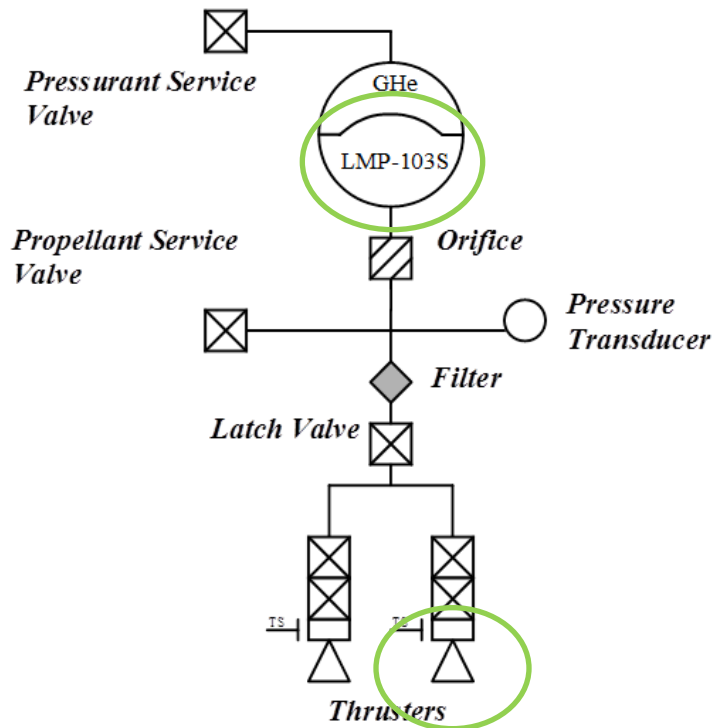
- LMP-103S is approved for transport by land, sea and air according to UN 1.4S
- LMP-103S has been transported on a commercial passenger airplane according to UN 1.4S (AWB 11-7-23910 795) and as air cargo with the PRISMA satellites to the launch site



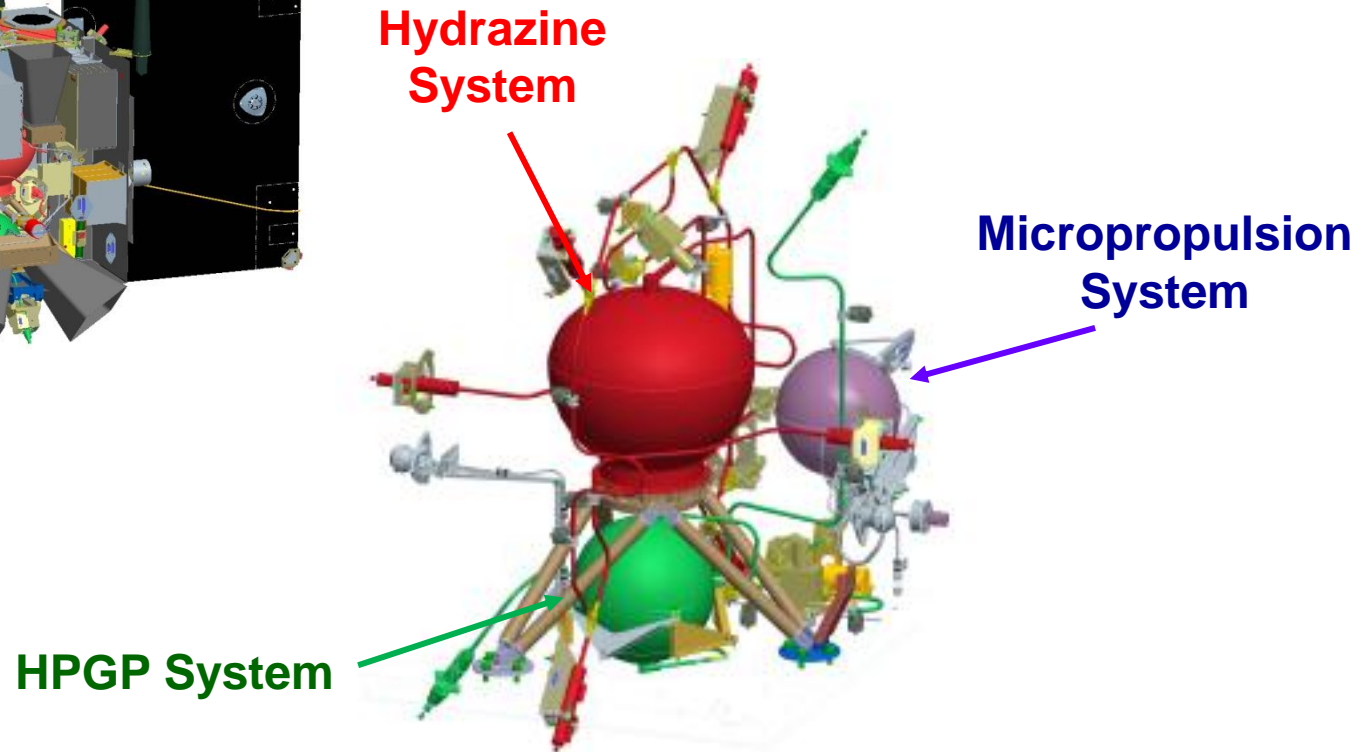
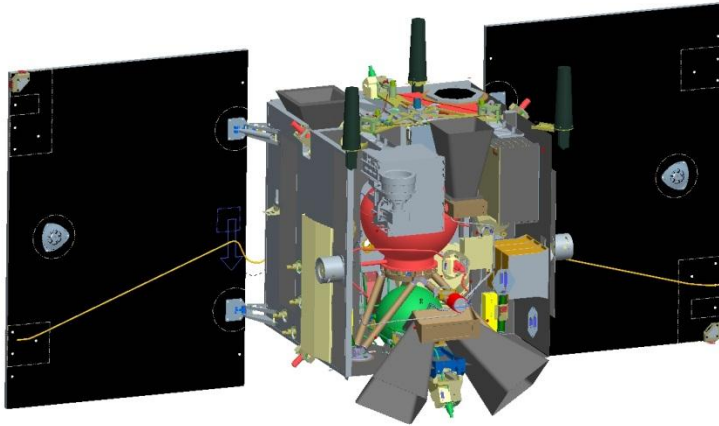
1 N HPGP Thruster



HPGP Propulsion System



PRISMA Flight Demonstration



PRISMA Launch Campaign

Spacecraft Loading

Loading PRISMA with LMP-103S (HPGP)



Loading PRISMA with Hydrazine



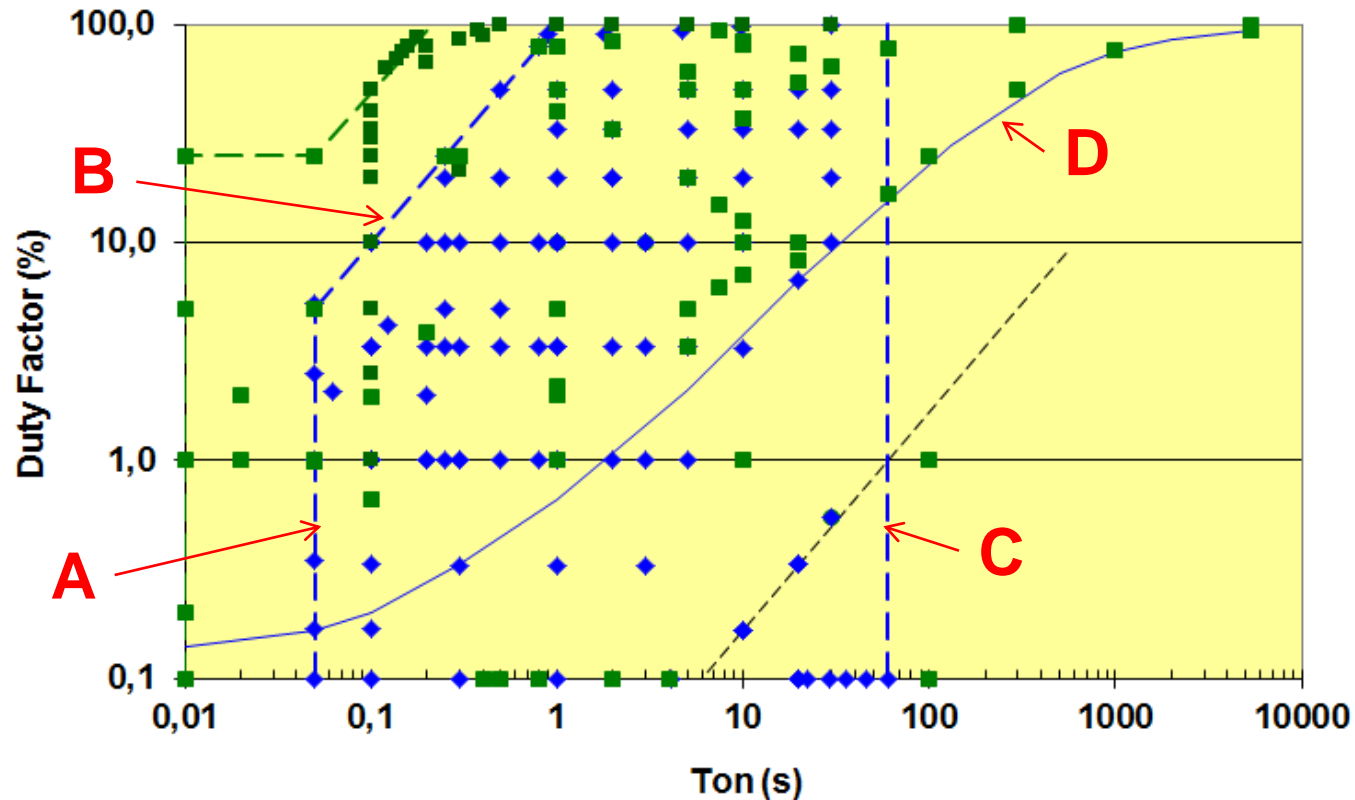
**PRISMA/PICARD Launch on Dnepr
from Yasny launch base
June 15th, 2010**



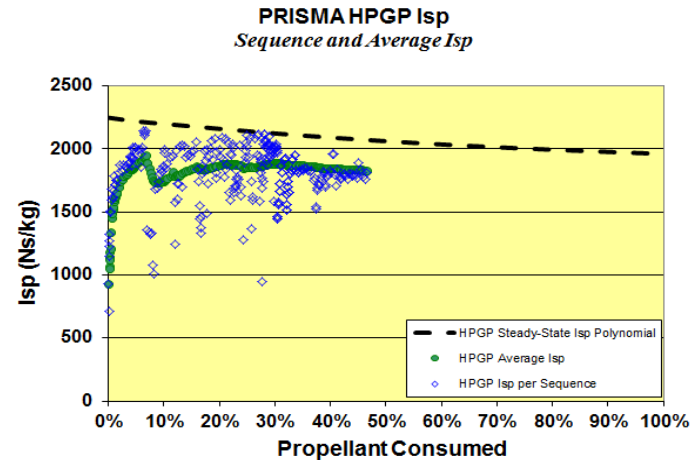
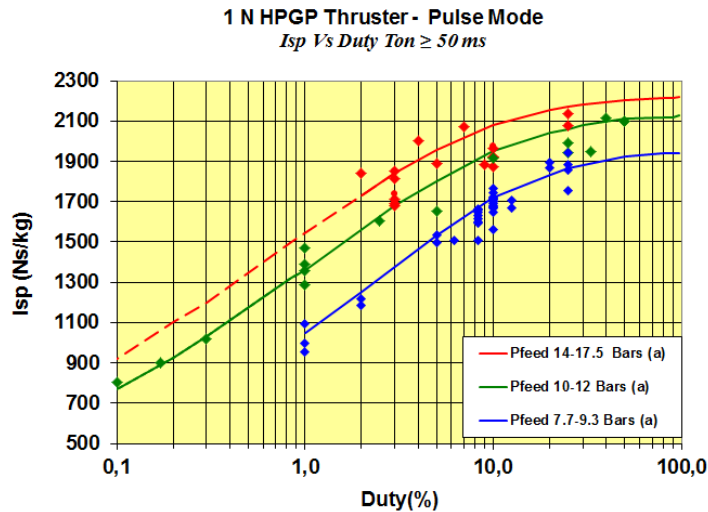
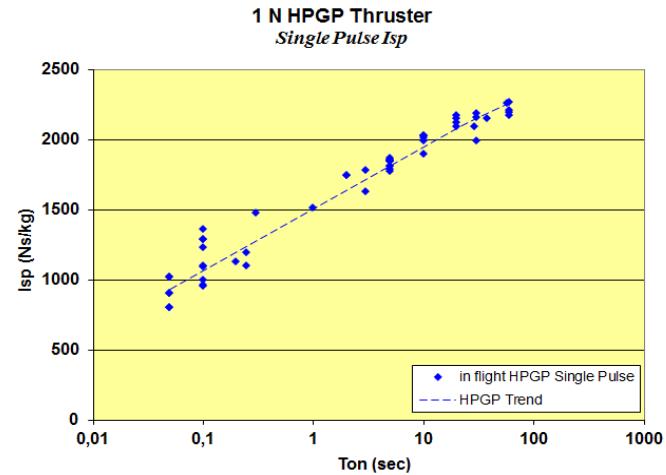
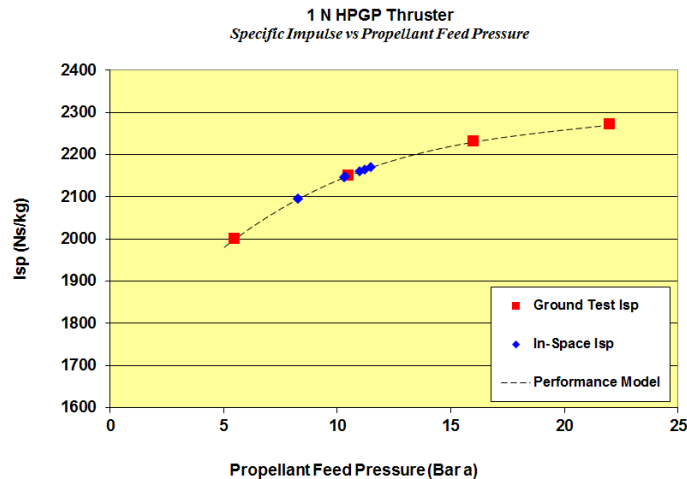
1 N HPGP Thruster

On Ground and In-space Fired Sequences

Duty Factor vs T_{on}



In-Space Performance Results



1 N HPGP Demonstration Life

1 N HPGP Demonstrated Life		
	On Ground	In Space
Propellant Storage Life <i>(In a propulsion system)</i>	> 5.5 years <i>(ongoing)</i>	> 1 year <i>(ongoing)</i>
Number of fired pulses	60,000	> 50,000*
Number of fired sequences	1500	> 363*
Longest continuous firing	1.5 hours	> 60 s, (75 s)
Accumulated firing time	24 hours	~ 3 hours*
Propellant throughput	25 kg	> 3.5 kg*
Total Impulse	50 kNs	

**Performed with two trusters*

HPGP Back-to-Back Comparison with Hydrazine

Specific and Density Impulse Comparison

<u>Steady-State Firing:</u> I_{sp} for last 10 s of 60 s firings		6-12 %	Higher I_{sp} than hydrazine
		30-39 %	Higher Density Impulse than hydrazine
<u>Single Pulse Firing:</u>	T_{on} : 50 ms – 60 s	10-20 %	Higher I_{sp} than hydrazine
		36-49 %	Higher Density Impulse than hydrazine
<u>Pulse Mode Firing:</u>	T_{on} : 50 ms – 30 s	0-12 %	Higher I_{sp} than hydrazine
Duty Factor: 0.1 – 97%		24-39 %	Higher Density Impulse than hydrazine

Mission average improvement with HPGP compared to hydrazine:

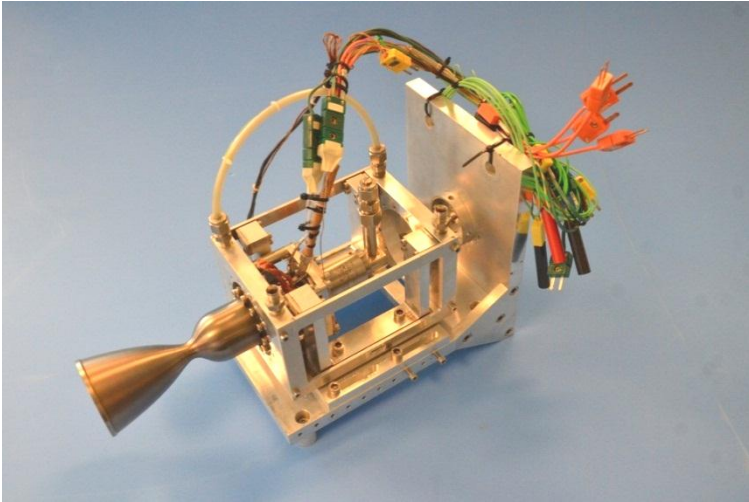
- I_{sp} + 8%
- Density Impulse + 32%

Conclusions from PRISMA mission

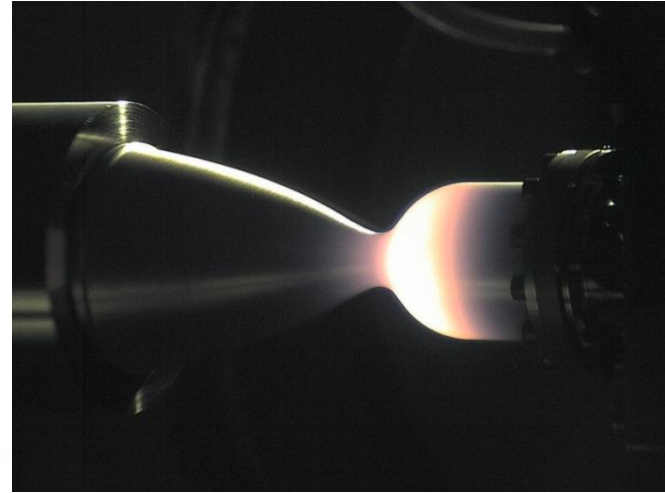


- All mission objectives for the HPGP in-space demonstration have been successfully achieved, thus TRL 7 has been met
- The PRISMA launch campaign demonstrated significant reduced risk, lead time and cost using HPGP
- The PRISMA mission is continuing

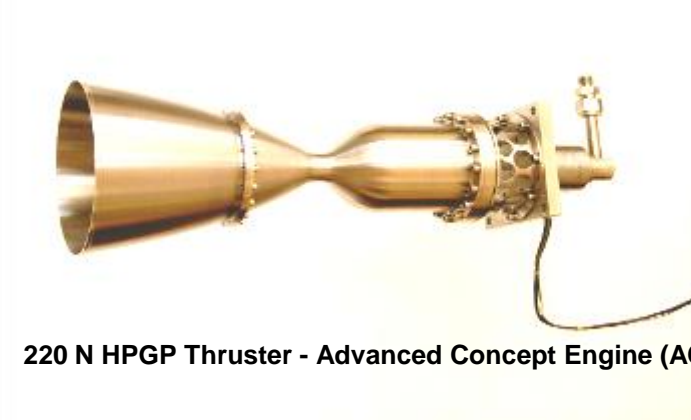
Scaling to Higher Thrust Levels



50 N HPGP Thruster in Thrust Balance



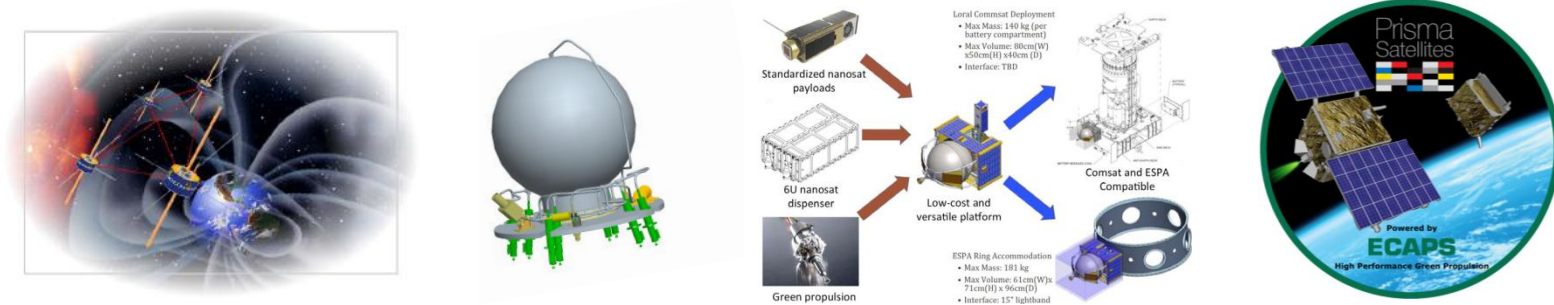
50N HPGP Thruster in Hot Firing Test Chamber



220 N HPGP Thruster - Advanced Concept Engine (ACE)

PRISMA paves the way for HPGP

ECAPS is a world leader in environmentally benign Space Propulsion



ECAPS is represented by ATK and MOOG for marketing and sales in the US.



MOOG





Thank you!